# Dynamic Modeling and Calculation of Self and Mutual Inductance between a Pair of Coils for Wireless Power Transfer Applications using ANSYS Maxwell

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**Abstract:** In this paper and in depth analysis of modeling and simulation of a two coil wireless power transfer system consisting of Transmitter coil and Receiver coil separated over a distance is described in detail using industry standard ANSYS Maxwell simulation tool. Where in dynamic calculation of self and mutual inductance of the coils is computed by assigning distance between the two coils as an variable, "dist" which is used for sweeping analysis, which makes the analysis simpler and increases the computational speed of the self and mutual inductance calculations. It is also proved that as the distance between the Transmitter and Receiver coils increases the Mutual Inductance coupling decreases and vice versa.

**Index Terms:** Wireless power transfer (WPT), ANSYS Maxwell, Transmitter coil (Rx), Receiver coil (Tx), Mutual Inductance coupling.

## I. INTRODUCTION

Wireless power transfer has been an research area for quite a few decades and recently lot of weightage has been given to carry out advancements in the field of wireless power transfer as it is considered to be more efficient in power transfer when compared to conventional modes of power transfer such as using cables etc.,[1] . Hence there is a serious demand for WPT based applications as the technology advances. In this paper, dynamic modeling and analysis of a simple two coil type wireless power transfer module is designed using ANSYS Maxwell software and the coefficient of Mutual inductance coupling, M between two coils isdynamically calculated for a range of distance. Hence before designing a product in real time it is modeled, simulated and analyzed in a high performance efficient tool like ANSYS Maxwell.

## II. DESIGNING OF INDUCTANCE COIL

Since a minimum of two inductive coils have to be designed for wireless power transfer to be possible. The designing of one such inductance coil is described which is called a Transmitter (Tx) and the same analogy applies for the Receiver coil (Rx) except for the reduction in dimensions. For most of the wireless power transfer applications Helix coil is preferred for Inductance coil designing [2]. The modeling is carried out in ANSYS Maxwell electromagnetic simulation package with the time domain specification chosen as transient analysis.We know that the Inductance of the coils must be large so as to obtain better Mutual coupling, which is with reference to the Equ. (1). Hence the Mutual coupling coefficient, M must be large for power transfer capabilities [3].

$$M = k \sqrt{L_1 L_2} \quad (1)$$

Where, M–Mutual Inductance in henrys

K – Coefficient of coupling
$L_1 L_2$– Inductance of coils in henrys

### A. Designing Transmitter coil (Tx)

Maxwell's polygon helix library under the used defined primitive toolbar is opted for the Inductance coil design and the cross-section of the coil is made circular since it results in efficient wireless power transfer capabilities.
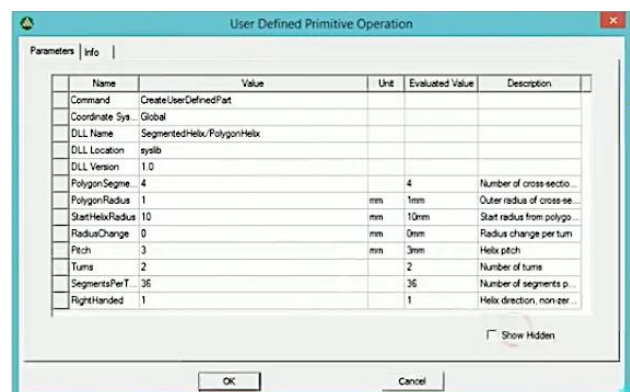


Fig 1. User defined primitives operation

Design parameters:

1) Polygon segment: Number of polygons for the coil.
2) Polygon radius: Radius of the cross-section of the coil.
3) Start helix radius: Defines the radius of the first turn of the coil.
4) Radius change: Difference of distance between consecutive turns of the coil.
5) Pitch: Defines the height of the helix in z-direction, with the coil on the x-y plane.
6) Turns: Total no of turns defined for the coil.
7) Segment per turn: Number of segments per turn.

Design of a Circular Transmitter (Tx) coil:

1) Polygon segment: Value assigned is zero, for a Circular cross-section of the coil.
2) Polygon radius: 0.5mm radius is defined for the cross-section of circular coil.
3) Start helix radius: 5mm radius is assigned for the first turn of the coil.
4) Radius change: A radius change of at least twice the polygonal radius is defined and in addition to it 0.05mm is added for isolation between the turns of the coil.
5) Pitch: It is assigned zero, as we want a perfectly circular cross-section in the x-y plane.
6) Turns: Ten turns is defined for the Transmitter coil.
7) Segment per turn: Thirty six segments per turn is assigned.

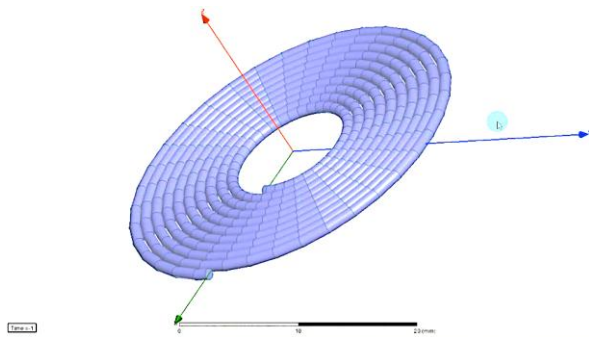Material assigned for the Transmitter (Tx) coil is copper.



Fig 1.1. Transmitter coil (Tx) is designed using the user defined primitive library of Maxwell.

Hence, the Transmitter coil (Tx) is designed for the following parameters and it has a center of P(0,0,0) on the cartesian coordinate system and is as shown in the Fig 1.1.

B. Designing Receiver coil (Rx)
The designing procedure of the Receiver coil (Rx), is same as discussed above for the Transmitter coil (Tx). Except for the slight modification in the design parameters such as decrease in number of turns for the Receiver coil (Rx)and modification of other parameters so that it results in an overall reduction in the size of the coil. Since for the wireless power transfer analysis the excitations and boundary conditions have to be applied for the coils, the terminals have to be laid out from the starting and the ending ends of the Transmitter coil (Rx) and Receiver coil (Rx). Hence to reduce time in designing the Receiver coil (Rx), duplication of the Transmitter coil is done using the Move option on the Maxwell's toolbarand it is placed at a distance of $P^1(0,0,z)$ from the Transmitter coil which is at the center of the cartesian coordinate system, P(0,0,0). The wireless power transmission system consisting of Transmitter coil(Tx) and Receiver coil (Rx)is as shown in Fig 1.2. The distance between Transmitter and Receiver coil is assigned as a variable called "dist" through which the distance can be varied dynamically for Mutual Inductance calculations.
The terminals for the Receiver coil are designed in a particular manner, where the distance of the terminals of
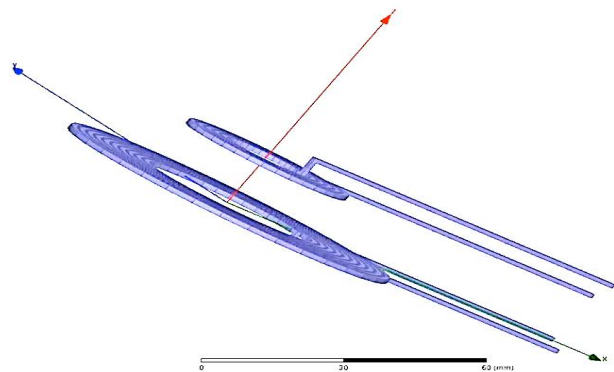


Fig 1.2.Transmitter coil (Tx) and Receiver coil (Rx) separated by a distance

the Receiver coils from the x-y plane also get modified when the distance between the Transmitter and Receiver coil changes. After the terminals have be laid out from the respective starting and ending ends of the Transmitter and Receiver coils, boundary conditions are laid out with air as an medium for the wireless power transfer system and also ensuring that the four terminals obtained from the coils are touching the face of the boundary. These are necessary if one is plotting the field vector, $\vec{B}$ for the entire wireless power transfer system. But for calculation of Mutual Inductance these are not required and hence omitted.
Transmitter coil is usually designed for larger dimension with respect to the Receiver coil as the Transmitter coil receives the power and transmits to the Receiver coil.

Specifications for the Receiver coil (Rx)
1) Turns: Five turns are defined for the Receiver coil.

All other specifications are similar to that of the Transmitter coil and the material used for the Receiver coil is also copper.

### III. SIMULATION OF WIRELESS POWER TRANSFER SYSTEM

With the Transmitter and Receiver coil designed and separated by a variable distance "dist" the simulation is carried out to find out the Self and Mutual Inductance coupling between the coils. Rather than calculating Self and Mutual Inductance coupling coefficients for every iteration of distance values. We use the pre-defined variable "dist" as an parameter for performing sweep parameter analysis so that for every iterative values of the distance which is assigned to the "dist" variable, the Self and Mutual Inductance values are automatically calculated in the background of ANSYS Maxwell's engine and after the simulation is completed the data is obtained through a Table which gives information about the Self and Mutual Inductances values for different values of distance which were initially assigned to the "dist" variable while performing sweep parameter analysis. The detailed procedure of obtaining the Self and Mutual Inductances values through the sweep parameter analysis is described:

A. Sweep parameter analysis
In the Project Manager window of ANSYS Maxwell, right click on the Optimetrics, add parametric analysis and go to

the tab sweep definitions and click on add option and select the variable "dist" as the parameter for sweep analysis and choose decade count for parametric sweeping since it can compute the resultant value with less number of iterations, with the following start, stop and step values as shown in Table 1. The Maxwell's setup sweep analysis is as seen in Fig 1.3.After specifying the sweep parameters, the file is saved in Maxwell and the Run button on the toolbar starts the simulation.

Table 1. Sweep setup for the parametric variable "dist"

| | | |
|---|---|---|
| Start value | 4 | mm |
| Stop value | 30 | mm |
| Step value | 5 | |

As described earlier the Self and Mutual Inductances of the coils are calculated for every iteration for the sweep parameters specified for the distance variable "dist". Once the simulation is carried out the results are viewed by right clicking on Data Table of the Results tab of the Project Manager window of Maxwell. After right clicking on the Data Table, select Update Report and theresults can be seen from the generated tabular column, whichis shown in Table 2.

Hence, from the simulation results it is observed that, column 3 is an indication that there is no Mutual Coupling between the Transmitter coil and the Receiver coil, hence the coupling coefficient,$M = 0$ and therefore it conveys, Self coupling of the respective coils occur as a result we get a value of 1. From column 4, it can be seen that as the distance between the Transmitter and Receiver coils increase the Mutual Coupling coefficient,M decreases and vice versa.

From column 5, it is observed that the net coupling coefficient value is a sum of Self and Mutual Inductance of the other coil as well and the value of the net coupling coefficient depends upon the direction of the current in the Transmitter and Receiver coil. Suppose if the current direction in both the coils is same then it results in additive type of Mutual coupling and if the current in the Transmitter and Receiver coils are opposite with respect to each other then it results in subtractive type coupling. Hence verifying the law of wireless power transfer to be valid using ANSYS Maxwell.



Fig.1.3 Sweep parametric analysis window from Maxwell's UI

| | dist [mm] | Matrix1.CplCoef(Rx_1,Rx_1) Setup1 : LastAdaptive | Matrix1.CplCoef(Rx_1,Tx2) Setup1 : LastAdaptive | Matrix1.L(Rx_1,Rx_1) [nH] Setup1 : LastAdaptive |
|---|---|---|---|---|
| 1 | 4.000000 | 1.000000 | 0.324804 | 988.377200 |
| 2 | 6.339573 | 1.000000 | 0.293069 | 996.422900 |
| 3 | 10.000000 | 1.000000 | 0.246804 | 990.010000 |
| 4 | 10.047546 | 1.000000 | 0.246179 | 990.291200 |
| 5 | 15.000000 | 1.000000 | 0.190036 | 990.657700 |
| 6 | 15.924287 | 1.000000 | 0.180922 | 990.291700 |
| 7 | 25.238294 | 1.000000 | 0.108946 | 996.280700 |
| 8 | 30.000000 | 1.000000 | 0.084520 | 996.449000 |

Table 2. Self and Mutual Inductances of the wireless power transfer system

## IV. CONCLUSION

Hence form the simulation of wireless power transfer system carried out in ANSYS Maxwell software, it is clear that as the distance between Transmitter and Receiver coil increases the     coefficient of Mutual coupling decreases and vice versa. ANSYS Maxwell is an industry standard electromagnetic simulation platform wherein complex electromagnetic systems can be analyzed before implementation, which proves to be cost effective and time saving.Wireless power transfer finds its applications in Battery charging systems, Electric vehicle technology etc., Hence because of these advantages wireless power transfer systems will be preferred over conventional power transfer methodologies in the late future.

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[3] A.B. Kurs, A. Karalis, R. Moffatt, J.D. Joannopoulos, P.H. Fisher, and M. Soljacic, "Wireless Power Transfer via Strongly Coupled Magnetic Reso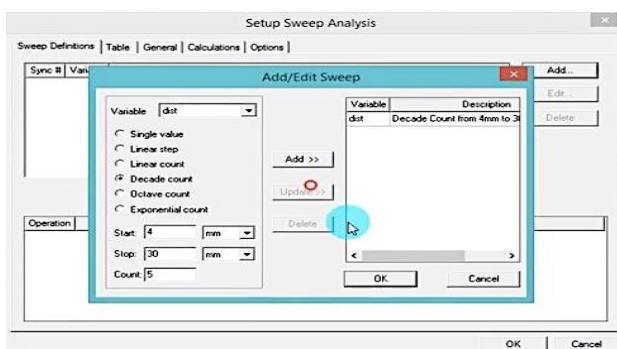nances", Science, 317, pp. 83-86,(2007).